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An Overview of Picture Archive and Communication Systems

by

Steven Dzik

Dave Hill

John Schwebel

INTRODUCTION

This report is meant to be a summary of the reasoning behind a digital network-based system for picture archiving, communication, and management in a radiology department. It contains a description of the assumptions describing the departmental workload, an idea of the difficulties involved, and a statement of current thinking on the subject. Hopefully, this report will serve as a basis for discussion and for criticism of any particular models that are proposed. This report does not, however, discuss the details of current Siemens proposals being made in Erlangen. We have used published papers for estimates of radiology department loads - see the references. Many of these numbers are open to question.

I. PURPOSE

A. REPLACEMENT

The aim of building a digital radiology department is to replace and improve upon the current system of analysis and management of images. Many of the diagnostic modalities - CT, NMR, Ultrasound, Nuclear Medicine are already digital; others, especially conventional x-ray, are potentially digital. Currently, the digital images are photographed and analyzed from film; a digital department would avoid film , normally, and analyze directly on CRT tubes.

The current system involves light boxes throughout the department, readily accessable to everyone. Films are stored in jackets or envelopes, one or more per patient, kept either with the patient records or in film archives.

B. EFFICIENCY

If the archiving functions - storage, retrieval, cataloging - were automated, the loss-rate of 5 to 10% would be almost eliminated. Further, the images could be available on demand, eliminating messenger delays and searches. They could be used by several people at once. Efficient use would be made of physician time, and the diagnosis delay would be reduced. Repeated exams should be minimized.

C. IMPROVEMENTS

Patient care should be improved through more rapid, more available, and more thorough diagnosis than currently possible. Consultation among specialists should be encouraged. With all images digital, correlation among different modalities can be performed if the viewing station knows the coordinate systems. Images can be easily magnified, rotated, and processed. Contrast information now lost in filming is kept available. Images can be reformatted to create views not originally imaged. Reports can be entered with the images.

D. COST SAVINGS

Pressures on hospitals to contain costs are increasing, and many people hope that a picture network could significantly reduce costs. Aside from efficiency considerations, some personnel associated with the current manual system could be eliminated, the amount of film used greatly reduced, and less storage space required. Any network will, however, have its own operating costs and archiving costs, which should be less than the current system.

E. DEMANDS

The dawn of the computer age has left many customers with the belief that the computer can do anything, and interconnection seems like a way of finally solving the incompatability problem of the individual modalities. A properly designed network has the potential for managing growth and allows hospitals to retrieve information conveniently for research projects.

II. MODEL OF CURRENT SYSTEMS

A. EXTENT OF DIGITAL IMAGING

Currently, CT, NMR, Nuclear medicine and Digital Subtraction Radiology are digital. All typically use a mini or microcomputer, have some form of video output, are photographed, and may be digitally archived. Ultrasound is just becoming digital. Conventional x-ray is currently not digital for cost, historical, and spatial resolution reasons. If conventional x-ray becomes a digital modality, the amount of data involved is several times more than that from all other modalities combined.

B. SIZE

How large is the imaging problem? The University of Kansas[1], Mallinckrodt[2], and NYU[4] have published some numbers representing their case load. Table 1 contains a somewhat modified version of these numbers, which should be representative of a 600 bed hospital. Numbers of images created and archived are converted to CT equivalents, where one CT image is 512 words x 512 words x 16 bits, or approximately .5 Megabyte. Clearly the numbers, which total 6700 CT equivalent images archived per day, are dominated by digitization of conventional x-ray, which is assumed to be a 2048 x 2048 x 12 bit picture.

After the study has been viewed at the creating modality, it will be retrieved for viewing an average of 5 times, most likely in the first day or two after the study is made. While the patient is in the hospital or actively under treatment, the study is kept available for easy access; in about two weeks, after the patient leaves, it is, or can be, sent to an archive for storage.

The number of viewing stations varies. Large sets of light boxes exist, with several in a central area and at least one each with the major modalities and in therapy planning. Areas separated from the radiology department have less elaborate stations, such as in the operating room, emergency room, trauma center, and various offices. Mallinckrodt stopped counting lightboxes when it reached 2000. Clearly, one cannot afford to replace each of these with a workstation. One might expect 10 major facilities, and many less elaborate ones.

C. IMAGE USAGE

Images are primarily used for diagnosis at or near the creating modality either with films or with the viewing capability of the equipment. They are also taken to more central areas, read individually, used for conferences, and compared to other modalities. If appropriate, they are taken to the operating room, therapy planning, or another treatment facility. They may be shown to the referring physician, and copies of the entire study or relevant parts made for him. Copies may also be made of particular cases for research or teaching files. After the patient has left active treatment, the images are held in an envelope with the patients name and ID. They are filed in a file room, from where they may be later retrieved for research reasons, for repeat-visits of the patient, or for following the process of care for an illness.

D. FUNCTIONS USED

Typically the bulk of images are scanned quickly and the few of interest extracted for closer examination. Many images can be displayed at once, and the selection of those of interest quickly made. Since film has preselected contrast and magnification, such parameters cannot be varied. In comparing various images, anatomical landmarks or position markings on the film are used as references. Orientation is varied by rotating or turning over the films. Measurement is done with a ruler, using any distance information recorded with the image or known from standard magnification of the device used. Regions are marked with pen for later reference. Magnification, if used, would be through external lenses.

E. PATIENT TRACKING AND MANAGEMENT

Most hospitals have an information and billing system for patient record keeping, typically based on an IBM computer. Some radiology departments also have their own system for keeping track of patients in their own area, as well as statistics on room usage and film location. These systems, typically using multiple terminals with low data rates, are locally designed and implemented and are not interfaced to the diagnostic devices themselves. Systems for generating reports vary from purely manual systems to those like SIREP and ones which record reports over telephone lines for later transcription, but store the voice digitally, so that a given report, or earlier one, can be accessed by dialing particular codes.

F. STRENGTHS OF THE PRESENT SYSTEM

The current system allows rapid access to many images - a radiologist can insert a film in a light box in a second or two; for some modalities that one film may have many images. Once placed, the images can be scanned quickly, an overview formed, and the ones of interest chosen. More than one person can view the images at once. Selecting and marking is easy and fast. There are no format problems - anything which has to be photographed can be displayed. The images can be easily carried from place to place. Films can be readily duplicated. The system works with unskilled labor and is never totally disabled. Finally, the system is a familiar, integral part of departmental routine.

G. WEAKNESSES OF THE CURRENT SYSTEM

With a manual system, images can be easily misplaced, lost, or stolen, a problem which affects 5 to 10% of the images after the first few days of use. The system is highly manpower intensive, and film is also expensive. One must be skeptical, however, at current cost estimates of a network system. Retrieval of images whose location is known can be very slow, from a few minutes to several hours.

For diagnosis, film storage has lost much of the available data by choosing a particular contrast window. Evaluation tools such as measurement are only marginally possible, and picture processing is not available. Correlation is possible but lacks certainty. There is really no good interface between the images, the exam, and the patient management and recording system. Reports are not readily available.

H. COSTS

Little information has been published on the cost of running a radiological film archive. The available information is hard to compare and is contradictory. There seems to be agreement that it costs on the average between $10-11 to put a radiological image study on film. For a hypothetical hospital that does 70,000 studies a year this comes to $700,000. There is no agreement whatsoever on the costs of storing the films and accessing them.

This depends on, among other things, how often the images are retrieved from the archive, the cost of hospital space, and the total amount of labor involved in accessing images and maintaining the archive; these values are hard to quantify.

The following figures have been derived from approximations from various sources. For a 70,000 study/year radiology department the space for the film archive costs about $200,000/year. It would require about 15 full-time employees costing about $20,000 each per year counting benefits. Film jackets and shelf space cost about $.30/study or about $30,000/year. Allowing for miscellaneous and uncounted expenses this comes to about $600,000/year. Thus, the film archiving system costs this hospital about $1.5 million/year.

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Table 1

	CT	NMR	N	U	DSR	DR(CHEST)	DR(ELSE)
IMAGES /CASE	15-50	15-50	7-10	30-42	10-60	2	2-16
IMAGES /CASE AVERAGE	30	30	8	40	30	2	8
IMAGE SIZE	512(16)	512(16)	256(16)	512(8)	512(10)	2048(12)	2048(12)
CASES /DAY	30	15	50	20	15	100	100
IMAGES /DAY	900	450	400	800	450	200	800
IMAGES (CT EQUIVA-LENT)	900	450	100	400	280	2400	9600
IMAGES ARCHIVED /CASE	30	30	8	40	5	2	2
IMAGES ARCHIVED (CT EQUIV)	900	450	100	400	45	2400	2400
DATA ARCHIVED (MByte)	450	225	50	200	22	1200	1200

III. REQUIREMENTS

The requirements are meant to provide criteria for evaluating and guidelines for designing a proposed system. They are qualitative and subjective in many cases. For any proposed system certain quantitative properties, such as the number of images handled by the system, will be required.

A. USEFULNESS

In order that it be used, the system must minimally perform the function of the model of current systems. Thus, its capabilities must include access to images at viewing stations for diagnosis, archiving and management of images in image libraries, and transport of images for distribution to image users.

Besides having the basic capabilities of the current model, the digital image system should replace film copies of images in most cases. Film development and management costs should be significantly reduced.

The system should be easy and convenient to use, so that the radiologist use it and are comfortable with it. The radiologists' needs should be th principal driving influence and evaluation criteria for the design. Extensive retraining must not be required.

B. AVAILABILITY

The system must be available as needed for viewing, archiving, and distributing images. There should be enough work stations or viewing stations so that the availability of images for viewing is comparable tc the availability of film at lightboxes in current systems.

In addition, the system must provide access to images simultaneously at different stations. It must also support the enhanced image evaluation and display functions by providing various copies of a stored image. There should be rapid response to access images for viewing, storing, and transportation. The capacity requirements must be adequate to handle the number of images stated for the system with the required response.

C. RELIABILITY

The network must be available at least ninety-nine percent of the time. Unscheduled network downtime should be no more than one hour per month. During this time, manual procedures using floppy disks, magnetic tape, or film should be available to replace the functions of the network. Scheduled downtime is permitted during off-business hours. However, part of the network or a backup facility must always be available for critical image retrieval.

Image data sources must be independent of the network and be able to function even with network failure. Data sources will require manual (off-network) backup for images from the current cases. The network should be resistant to the failure of attached stations.

D. SECURITY

Access should be limited to authorized users, with levels of privilege provided. Since the network can be connected to other networks, access restrictions are required.

Data integrity is required. The data retrieved must be the same as the data requested, i.e. image studies and reports must not be corrupted.

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E. FEASIBILITY

The feasibility of the network must be demonstrated by showing that it is cost-effective, affordable, competitive, and timely. The overall system must deliver features that cannot be provided more cheaply by other means, while still meeting the budget requirements of the users. The system must be designed to incorporate advances in technology, be state of the art when completed and released and be released in time to meet the customers' needs.

F. CONFIRMATION TO STANDARDS

The network must conform to standard formats, interfaces, and protocols. There should be a standard format for images on the network which should be compatible with industry standards in effect at the release of the system. The interface to stations should be standard for all types of stations. In those areas where no standards exist, an internal standard should be specified, used, and made publicly available. The network design should conform to the International Standards Organization(ISO) recommendations.

G. CONNECTABILITY

The system should allow interfacing to various equipment types, including existing Siemens as well as other manufacturers' devices. The system should be capable of allowing interconnections to other hospital systems, local area networks, and wide area networks. Patient management systems and hospital administrative systems should be capable of accessing the network. Connection to other networks should be provided through standard gateway protocols.

H. CONFIGURABILITY

The system must be able to operate with a small initial configuration and to expand modularly to a large complete system. It must be adaptable for various sites with different access, storage, capacity, and usage characteristics.

I. ARCHIVAL PROPERTIES

The archive must be able to store a specified number of images and data at various levels of performance. It is likely that short-term, intermediate-term, and long-term storage will be needed. The length of retention of an image must be a system parameter. The access speed performance may depend on the current level of storage. Accessing an image should not require an explicit file name or location. Images must be available by case and not just by image. The physical location of an image will be independent of the name used to access the image.

J.DISPLAY PROPERTIES

Stations must be provided for displaying, evaluating and accessing images. The maximum number of images capable of being handled and presented to the user on each type of station must be specified. The design of the system must take into account the number of images required by varying size institutions. Using these figures, the number of stations required, the number of users supported by each station, and the total number of concurrent users for which the system will stay within its performance limits must be specified.

IV. DESIGN PRINCIPLES

The digital network-based system must conform to generally accepted design principles for large hardware/software systems.

A. FLEXIBLE/MAINTAINABLE

The system should be designed to be flexible, modular, and extendable. The numbers of each type of station on the network should be variable within limits. The software should be written in a device-independent way so that the main modules support "virtual" devices. The mapping from virtual to physical devices is contained within a replaceable device-dependent module. The data transported on the network should include self-describing information, so that they can be converted from the network form to device-dependent forms. The main modules of the software should be independent of the data types or formats chosen. Thus, the network should be adaptable to data-type changes, device changes, and configuration changes. For example, adding or deleting a station should be easy, and must not require changes to the system software.

B. RELIABLE

Reliability and fault-tolerance must be design principles. Redundancy of hardware, such as of the archival media, may be used to insure reliability.

C. DISTRIBUTED ARCHITECTURE

The system must be designed to support a distributed architecture of display stations, storage and retrieval elements, and management functions. Within that architecture, some of these functions may be centralized or distributed to various elements of the network.

D. CONSTRAINTS AND CRITICAL PATH-ANALYSIS

The design process should identify the constraints on the networks and the critical paths of the network. The trade-offs which have been made in the design between response, capacity, cost reliability, and user-friendliness must be explicitly identified.

V. SYSTEM COMPONENTS

A PACS network consists of several major components: data sources, data storage, data management, work stations, data transport and network architecture. Each is described below. The general term for a data source, data archive or a work station is station.

A. Data Sources:

Data sources are the diagnostic systems that produce the images that PACS systems handle. Since the current CT scanners, NMR scanners, and other imaging devices were not designed with the intent of being connected into a network, many of them have severe limitations as stations.

The communications activities of a data source should not interfere with its normal functioning. It should be able to transfer data quickly and transparently. It should be able to service the network's request for data and be able to do automatic archiving.

These capabilities require a permanent process running concurrently for communications, which many present data sources cannot do. In addition, these processes could be fairly large and might not fit into memory, where they must be resident to provide adequate response time. Many data sources cannot transfer data fast enough for this application.

An external computer will probably be needed to interface many data sources to the network. This will be a place where network software can run and provide adequate communication facilities, thus minimizing changes to existing products.

Existing data sources will only be able to send data out on the network. Future products should be designed with PACS interfaces so that they will also be able to function as PACS work stations.

B. <u>DATA STORAGE</u>

If all the images in a PACS network are kept in one central archive, all the traffic in the network converges on one location. This creates a traffic bottleneck that slows down the entire network. It will probably be necessary to distribute the archive so that this bottleneck is avoided. In addition, different images are needed at different places, more or less often, and more or less quickly. A hierarchy of storage could accomodate different needs. This requires complicated software because the user does not always know the location of the data he wants. However, it eliminates the bottleneck and provides for more flexibility in the network design.

The main unit of data that PACS will deal with is the study. Users will rarely want to access a single image; rather, they will want to access an entire study. A study is generally defined to be all the data from an examination using a particular modality.

In this discussion the examples and figures we give are for a large radiology department with over 20 rooms in a 600-700 bed hospital. This is the situation in the University of Kansas and University of North Carolina Medical Centers~~, and Mallinckrodt.~~ These institutions have PACS projects underway and have analyzed their department's needs most thoroughly. The largest departments (like Mallinckrodt) would produce about 10GB/day if everything were digitized. The University of Kansas Hospital radiology department now produces between .25

and .5GB of image information in a day[2]. It is reasonable to expect this to go up to about 2GB per day in the not too distant future. Ten days' images seems a reasonable amount of data to keep on-line throughout the entire network.

The following is an example of a storage system to illustrate the issues involved in PACS data storage.(See TABLE 2).

TABLE 2. STORAGE HIERARCHY

LEVEL	LENGTH	SIZE(bytes)	RESPONSE-TIME MAX
local	hours	10^8	3 sec.
short-term	1-2 days	10^{11}	20 sec.
medium-term	5-10 days	10^{12}	1 minute
long-term	longer	10^{16}	30 minutes

The lowest level in the hierarchy is the local storage associated with each data source. This is where images are stored immediately after they are made. They are easily available at the data source console. Images are usually kept only a short time (a couple of hours).

Short-term data storage would probably be for 1 or 2 days, the time period when images are accessed most. This storage would be characterized by fast response which might be accomplished by storing images non-compressed, using fast devices, and by providing a high bandwidth between short-term archives and the stations most likely to need their images. Images would be available to the entire network on this and all longer term archives.

Medium-term archives would store images for up to 5 or 10 days, or for the length of a patient's stay in the hospital. Since these images would be used less often, quick access is not as critical as in short term storage. More centralization, usage of a cheaper storage technology, and storage of compressed images may be allowed.

Long-term archives would store images after 5 to 10 days or after the patient leaves the hospital. They would have the least stringent response requirements and the data would probably be kept off-line. The archive could be, and probably will be, distributed. There could be separate short-term archives for each different imaging modality.

Archive sizes will vary from about 10^8bytes for a local store to 10^{12}bytes for 10 day on-line storage in a fairly large radiology department. After that, images would be kept off-line for as long as there was physical space to keep them. The average time required to retrieve a study from short-term store should be on the order of twenty seconds. From medium-term on line store a couple of minutes is acceptable. Off-line accesses may take 30 minutes.

The response times will be faster to access the first image in a study and to access indices of the images in the database.

If the archive has been divided into short, medium, and long-term storage, the question arises as to when data should move up the hierarchy. A hospital also might not want to save everything; likewise, it might want to take some images off-line sooner so others can stay on-line longer. Data must also be able to migrate from long-term to short-term storage when a patient reenters the hospital. How these decisions will be made is an open question.

A critical factor in all of this is the kind of archival storage to be used. No commonly used technology can keep 50-100GB of data available on-line economically. Laser disks seem to be the most promising technology in the forseeable future. Individual laser disk platters of up to 10GB should be available in the next few years for under $100. The disks are about the size of a record album and would hold one day's images from the largest radiology department.

Another promising technology is digital film. Digital information can be stored very densely on film, about $1Mb/cm^2$. These films could be kept with patient records for long-term off-line storage. This is about 1/10 the density of laser disk technology.

A third promising technology is a high density magnetic tape drive. Currently, these cost about $120,000, but allow 9GB (unformatted) on a single tape.

Data compression can reduce the amount of data to be stored by a factor of 3 or 4, reducing network traffic at the same time. If image compression can be done quickly, it will be an important factor in making PACS more economical and useful.

References[2] and [3] analyze the current and projected costs of archiving images digitally using current technology.

C. DATA MANAGEMENT

A PACS system will hold a very large number of images; new ways must be used to access the data. The present system of referencing images using the volume name and image numbers is entirely inadequate when entire studies are being accessed from several machines or distributed archives. Users must be allowed to specify the images they want in some logical and consistent manner that is not modality or location specific.

There must be a way of finding out what information is available on a patient over the entire network and over all modalities. Image access must be available under several criteria (patient name, number, study, modality, or body part for example). Users must be able to find out whose (patient name, ID number) information is on the system.

The system will provide access to patient information and reports. Report generating facilities for system statistics will be provided. More general patient management functions such as billing, tracking, and room management are not required.

The system must be able to recover from errors and restore the data that were destroyed.

D. WORK STATIONS

A central part of the PACS concept is the work station. These are the places in the network where images are evaluated. They must be able to display images from all modalities and machines. There must be a large local storage for fast access to many images. Patient reports should also be available.

Evaluation tools necessary at the work station include: Rotate, translate, magnify, correlate,reformat, image process, image translate, statistics and survey.

Since these work stations replace the lightboxes currently used to look at images, more than one screen will be needed. The design must be such that more than one physician can look at the images comfortably. Most of these work stations will have to work without special air-conditioning.

Not all the work stations will need the complete set of features. Simple display stations, that can only display images, would be adequate in an operating room or in an office.

E. DATA TRANSPORT

The data transport network is the subsystem that actually carries the data from one place to another. Due to the large amount of data it handles, it must have a high bandwidth. The communication protocol must use the network's capacity effectively, providing the best response time for the largest number of stations and providing flexibility in handling different types of data.

Most current protocols are designed for applications very different from PACS. They are typically designed so that many stations sending short, sporadic messages over a period of time can effectively use communication facilities. In PACS applications, stations send and receive very large amounts of information in one burst and are then finished. The actual transmission of the data takes a perceptible amount of time [3]. Special or modified protocols will be needed for PACS. Analog channels would be useful for transmission of video information to low-cost monitors. These would be used where only display capabilities are needed.

Broadband coax cable and fiber optics seem to be the only media currently available with the bandwidth needed for PACS systems.

The following example will be used to illustrate the minimum data transport requirements for a PACS. The data are taken from an analysis done by Mallinckrodt [2]. They expect to retrieve 100 studies/hr with each study being about 10 MBytes. This comes to 8GBits of network data traffic per hour or about 2 MBits of network data traffic per second. Assuming that data communications software doubles the overhead, 4Mbits/second is required. Assuming a 6/1 peak to average demand ratio then a bandwidth of about 24 Mbits/second is required. A smaller department will need proportionally less bandwidth. A department 1/4 the size of Mallinckrodt would require about 6 Mbits/second. Data compression will reduce this requirement.

The result is the minimum bandwidth required for the total network in order to transport all the incoming data. This traffic can be distributed on several channels.

An alternate way to compute bandwidth requirements is from the point of view of user response time. First an adequate response time for retrieving one 10MByte(80Mbit)study must be decided upon (say 10 seconds). Network software and traffic will reduce the response time by a factor of 3 or 4. This results in a required bandwidth of 30 to 40 Mbits/second per channel(regardless of the size of the department).

There are, in reality, several different response times to consider. There is the time to receive and display the first image, the time to receive the entire study and the time to get all the information relating to a patient. It may not be required that all the information be available quickly if enough is available in a short time to allow the physician to begin the diagnosis.

F. NETWORK TOPOLOGY

A brief description of the most important topologies used for local area networks with advantages and disadvantages follows.

ETHERNET

All communication is on the same coaxial cable at one frequency. The stations contend for use of the cable. It is very simple and works well in low data rate applications. The network bandwidth is limited to the cable bandwidth of about 10MHz. System overhead reduces this quite a bit. In addition, the response time is related to the length of the cable.

RING

All the nodes are hooked up in a ring. Data is sent from one station to another until it reaches its destination. This allows more data to be sent than with an Etherenet since all stations can transmit in parallel. However, if one station goes down, the ring is broken and the whole network stops.

STAR

In a star all the network stations are connected to a central switch which does all the data communication. The bandwidth is limited because everything must pass through the central switch.

BROADBAND

The broadband architecture was specifically designed for PACS networks. In this architecture the transmission medium is a tree composed of broadband coaxial cable. All the stations are attached to the tree and have their own transmit and receive frequency. A frequency converter at the root converts the transmit to receive frequencies. The advantages of this are a very high bandwidth (about 300 MHz) and the ability to easily integrate analog channels. A disadvantage is that the bandwidth is allocated permanently for each station regardless of whether or not it is used.

HIERARCHY

Instead of having one network (of any architecture) it might be better to have several smaller subnetworks connected to one larger one, with each of the subnetworks having a high degree of independence from one another. Most of the data transfers occur with the subnetwork, and only a small amount of traffic goes between subnetworks over the main one. The response will usually be better because there is less traffic in each subnet. The major disadvantage is that the response is slower for transfers between subnets and requires more software for those cases.

HYBRIDS

A realized network may combine these designs. For example, each subnet may be a ring with the subnets joined together over Ethernet.

The network configuration must be flexible. It must be possible to add and remove data sources, workstations and archives. Diagnostics must be available to find problems, and network activity should be monitored.

G. CUSTOMIZATION

The system will be customizable for different installations. Customization will be part of the generation or design of the system and will not require software changes for each installation.

Textual data such as patient name and other patient management information will be of variable data type with identifying descriptors which the system should handle without modifications.

H. COSTS

A cost analysis for a PACS is not possible without a design. This discussion will not attempt to derive a single cost for a PACS system but to give a general idea of the costs of different aspects of it.

In an all digital radiology department the traditional lightboxes will be replaced by work stations which should be about as accessible as lightboxes are today.

These lightboxes have been put up over a long period of time and no one knows how many there are in any hospital. The hypothetical hospital in our calculations would have over 800 lightbox locations. Replacing each of these with a display station would be prohibitively costly; some compromise is clearly necessary. Most of these lightboxes are not used very often but they are always available. Nobody knows how many of these lightboxes are used simultaneously.

Each data source will need a network interface module. The archive will require one or more computer systems. Each network interface module would probably cost in the tens of thousands of dollars. Archives would cost hundreds of thousands of dollars. Installation of the network will be a major cost. Whatever medium is used will probably have to be installed in the walls and floors all through the hospital. Work stations will cost about $100,000. Converting to an all digital department would require digitizing the existing film library or having a transition period when both film and work stations are used.

The operating costs include the archiving medium. This should be on the order of a $100/day if laser disk technology is used. This is a very low price and represents one of the true savings in PACS.

There are also costs in keeping data on-line, beyond the fixed costs of the network. According to Dwyer [1], it costs about $7.00 to keep a study on line for 5 days. They have also estimated it costs about $100,000/year to archive on tape all the studies from a CT head scanner[2].

I. DIFFICULTIES

The preceding discussion summarizes some of the technical aspects of PACS networks. There are some very difficult technical problems in realizing such a network.

1. Either existing machines must be modified or special network interface processors must be designed and built.

2. Standard interfaces and formats need to be defined and converters have to be implemented so that images from various modalities and manufacturers can be viewed together.

3. The response times at the work stations must be small enough to make the system worth using.

4. For all their problems, photographic images, lightboxes, and folders are very convenient. They may be carried and kept any place. In a few seconds many images(representing millions of bytes) can be displayed simultaneously on one lightbox. A PACS system must approach this sort of convenience.

5. To be economically feasible one PACS design must work in many situations or be easily customizable, since every hospital has its own way of doing things. In particular, different hopsitals have different patient management systems. A PACS must be able to integrate most, if not all, of these.

6. A distributed, hierarchical, image data base must exist that can also access other computerized patient information. Images and studies must be able to be selected with several different identifiers or combinations thereof.

7. To be cost effective, the system must be built and finished in a finite amount of time for reasonable cost. It must work reliably. Enough hospitals must be able to afford it to make it profitable.

8. The product must not miss its market. It must be competitive with other systems and it must be relevant to the problems at the time it is available to buyers.

VI. RELATED PROJECTS

RISC - Radiological Information Systems Consortium is a group of hospitals and the Digital Equipment Corporation (DEC) who are developing an automated radiology information system. The system is currently under development. The first stage of this resulted in DECrad, which is under field-testing as of this writing (3/83).

3M - The 3M Corporation has designed and is selling a broadband image communication network. They particularly want to sell image format conversion devices.

There are a few PACs projects in progress - the most important are:

University of Kansas has a fiber optic ring network, with a few stations already on the ring.

University of North Carolina has a 3M broadband network in its initial stages.

Mallinckrodt is investigating PACS but has not yet started a full scale project.

Siemens has been involved in medical information systems before, the most important are:

SIREP - A patient-reporting system that is no longer being supported.

SOMATOM II data link - The SOMATOM II could be connected to an Evaluskop and images could be copied from one system to the other.

Victoria - Siemens has accepted a commitment in Victoria, British Columbia to design and build a digital radiology department. To meet that commitment, a group under Phillip Schipper is investigating the problems discussed in this report and proposing solutions.

VII. EFFECTS ON CURRENT PRODUCTS

There are hardware and software requirements on Siemens current products in order for them to be data sources on the network.

A. HARDWARE

There must be a hardware interface to the networks for each of the existing data sources. The interface must be capable of matching the characteristics of the network and of transmitting images from the data source. The physical layer interface to the network could be driven by a controller in the data source or by a standard interface device connected to the data source.

B. SOFTWARE

The current software must be enhanced to provide a software interface to the network. Commands should be added in the scanning system to provide file level image transfers to the network in a way consistent with the current software. Software for format and protocol conversion could exist in a standard network controller and be transparent to the driving program.

Strategies of handling data transfer from the network to the scanning system must be devised. Since the data source should not be dedicated to network operation, interrupts from the network should be handled concurrently with scanning. This should be easiest to implement in NMR, where a multi-process operating system is being used.

C. USE AS WORK STATIONS

In the long term, it is desirable to be able to use the evaluation consoles of current systems as work stations on the network. The software should be designed to be as device independent as possible, so that different devices can serve as work stations. A work station should operate with minimal local storage.

VIII. DIRECTION

A. PURPOSE

Given that interconnection of diagnostic devices will occur, the primary decision for Siemens is what part will it play in that development and when. Possibilities include:

1. Aggressive design and production of a full system, with a Siemens' possiblity for every component.

2. A cooperative design with another company, with that company acting as network supplier and Siemens supplying various components, including work stations and archive as well as carefully interfaced data sources. Patient management would be done either by the network company or by Siemens.

3. Build components and workstations and expect to interface to whatever comes along.

4. Work exclusively on data sources, and ignore the network phenomenon until a direction becomes clear.

5. Actively work against networks by emphasizing their shortcomings.

Alternatives 3,4, and 5 would require a prototype solution to meet Siemens' Victoria commitments, possibly by contracting with another company to provide that network.

B. OTHER MANUFACTURERS

Assuming that an active alternative is to be chosen, a collaboration on network design is needed immediately. Viable solutions to the connection of other manufacturer's hardware should be envisaged.

Publicly available formats and hardware protocols are needed.

C. COMPONENT PARTS

A work station is a component of every network scheme. Current designs should be reviewed, and the hardware and software required specified, so that costs and development time are understood. If at all possible, a version of such a workstation should be the display and evaluation station for any new product.

If conventional x-ray is to be digital, a choice must be made among digital video, area scanners, line scanners, and detectors of various types to provide a high quality, economical system. The full benefits of a local area network will not be realized without digital conventional x-ray.

For short-term and medium-term store, arrays of hard disks will be needed. Insuring reliability, enabling management, and avoiding access bottlenecks require careful design.

For the immediate future, the archival store will have to be magnetic tape. Improvement of the data compression scheme and implementing it in hardware can reduce the problems from unmanageable to difficult. Current development should lead to a viable choice between optical disk or high capacity magnetic tape. Clearly a digital image network system needs access to patient records and records of diagnosis, but does not necessarily need to have tracking and billing functions. The amount of patient management to be included must be determined.

D. NETWORK MANAGEMENT SCHEME

Potentially the most difficult, expensive, and time consuming product to develop is the software which performs the network functions. Optimizing it will surely impact the hardware design. Image management and patient management are closely associated, and both will be required in a functioning network. The costs of adapting present products to the network cannot be ignored.

E. PARTIAL IMPLEMENTATIONS

Interconnections among CT and NMR devices are easy in comparison to the full network task. A standard interface should be used. Connecting some of these devices to others by slow speed phone links would be useful. Similar to the CT-NMR case, cluster interconnections of several digital radiology products or nuclear medicine products should be tried. The work station development should continue, and it should be used stand alone or linked as an Evaluskop for our CT/NMR products.

F. FURTHER RESEARCH

It should then be possible to take the current concepts and attempt to do a detailed design using a task group from a number of the affected disciplines, to be sure that the expected performance can be met and to gain a clear understanding of the development timetables and costs.

Current concepts need to be widely reviewed within Siemens. The concepts and desired performance should be presented to a diverse group of radiologists and administrators for comments and suggestions, with the understanding that they are hearing about possibilities and not product.

IX. SUMMARY/CONCLUSION

Our customers think they want a fully digital department, and a number are making financial commitments to it. Adequate technology is available for all components except a long-term archive, and such technology is expected in the future. Networks will occur anyway; Siemens can attempt to direct the development and minimize its own difficulties. Careful design is necessary and urgent.

Siemens should emphasize the building of the work stations, the making of a digital x-ray system, and the designing of a network system in close collaboration or consultation with an experienced network company.

SIEMENS

REFERENCES:

1 - The Cost of Managing Digital Diagnostic Images, Samuel Dwyer, etc. Radiology, Vol.144,No. 2 ,P. 313-318 July, 1982.

2 - Study of a distrbiuted picture archiving and communication system for radiology. J.R. Cox, G.J. Blaine, R.L. Hill, R.G. Jost; SPIE Vol.318 PACS conference proceedings (1982)

3- A study of Photoelectronic-Digital Radiology-Part II: Cost Analysis of a Photoelectronic-Digital Versus Film-Based System for Radiology. Sol Nudelman, Jack Healy, Michael Paul Capp, Proceedings of the IEEE, Vol.70,No.7,July 1982

4- Image processing requirements in hospitals and an integrated systems approach. G.Q. Maguire etc. SPIE, Vol.318 PACS conference proceedings (1982)